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Abstract

Hirsch's h-index cannot be used to compare academics that work in different disciplines or are at different career stages. Therefore, a metric that corrects for these differences would provide information that the h-index and its many current refinements cannot deliver. This article introduces such a metric, namely the hI,annual (or hIa for short). The hIa-index represents the average annual increase in the individual h-index. Using a sample of 146 academics working in five major disciplines and representing a wide variety of career lengths, we demonstrate that this metric attenuates h-index differences attributable to disciplinary background and career length. It is also easy to calculate with readily available data from all major bibliometric databases, such as Thomson Reuters Web of Knowledge, Scopus and Google Scholar. Finally, as the metric represents the average number of single-author-equivalent "impactful" articles that an academic has published per year, it also allows an intuitive interpretation. Although just like any other metric, the hIa-index should never be used as the sole criterion to evaluate academics, we argue that it provides a more reliable comparison between academics than currently available metrics.

Introduction

In the past decades, academics and universities world-wide are increasingly subjected to monitoring and evaluation of research outputs. Although concerns about this "audit culture" are growing and many authors warn against its potentially perverse impact (see e.g. Adler and Harzing, 2009; Marginson 2007), it is unlikely that we will see a reversal of this trend. This leads to a natural interest in research evaluation methods and metrics that at least are as valid and reliable as possible. One of the more popular indices in this respect has been Hirsch's h-index (Hirsch, 2005), which in many contexts has supplanted the once ruling journal impact factor and is now widely accepted and applied in a variety of contexts (for an excellent brief summary see Bornmann and Marx, 2011). The Hirsch index has a definite advantage over the journal impact in that it considers the *actual* citation impact of an academic's published articles, rather than the *average* citation impact of the journal that the academic publishes in. However, like any metric, it is not without its flaws.

Hence, since the publication of Hirsch's h-index (Hirsch, 2005), the field of bibliometrics has experienced an almost bewildering explosion of publications proposing h-index variants. Most of these variants are designed to accommodate the h-index's shortcoming of ignoring citations in excess of the minimum needed given its value. However, if different citation levels for the same h-index are of interest, two perfectly good alternatives are readily available: the total number of citations and Egghe's g-index (Egghe, 2006). A key advantage of the h-index is its simplicity, ease of understanding, and ease of calculation, an advantage that is lost with its more complicated alternatives. Furthermore, many of the fractional h-index alternatives suggest a level of accuracy that is simply not present in the underlying citation data. Finally, in a review of 37 different h-index variants Bornmann, Mutz, Hug and Daniel (2011) conclude that most of them hardly offer any added information over the h-index and were in fact redundant.

A more troubling shortcoming of the h-index is that it cannot be used to compare academics that work in different disciplines, with different publication and citation traditions, or academics that are at different career stages (see amongst many others Bornmann and Marx, 2011). Therefore, a metric that corrects for these differences would provide information that the h-index and its many current refinements cannot deliver. This article introduces such a metric, namely the hI,annual (or hIa for short). The hIa-index represents the average annual increase in the individual h-index. Using a sample of 146 academics working in five major disciplines and representing a wide variety of career lengths, we demonstrate that this metric attenuates h-index differences attributable to disciplinary background and career length. We therefore conclude that the hIa-index provides a more reliable comparison between academics in different disciplines and at different career stages than currently available metrics.

The hIa has two additional desirable characteristics that are not shared by most other metrics, with the exception of total citations and the original h-index. First, it is easy to apply in practice. The hIa is easy to calculate automatically with information readily available data in all major bibliometric databases, namely the number of authors and the number of years an academic has been active. There is no need for any manual manipulation or reference to external data. Second, its simplicity makes it appealing to a lay audience. The resulting metric, the average number of single-author-equivalent "impactful" articles an academic publishes per year, is easy to interpret without needing to refer to the original definition or reference tables. Moreover, any user can easily replicate its calculations without the need for high-level mathematical skills. Hence we argue that the hIa compensates the shortcomings of the total number of citations and the original h-index, but retains the practicality and simplicity that has made these metrics appealing to a large audience.

In the remainder of this article, we review prior metrics that correct for disciplinary and career length differences and illustrate why they are not sufficient. We then present an empirical illustration of the hIa and evaluate its usefulness and limitations.

Metrics correcting for disciplinary and career length differences

In comparison to the multitude of metrics that attempt to correct the h-index by taking into account "excess citations" in the h-core, there are surprisingly few metrics that attempt to correct for either disciplinary differences or differences in career length. Correcting for disciplinary differences is essential as it has long been established disciplines do differ very significantly in terms of their publication practices. Zuckerman and Merton (1971) for instance found that disciplines differed quite dramatically in terms of their refereeing practices and in particular their journal rejection rates, with the Social Sciences and Humanities reporting far higher rejection rates than the Sciences. Other aspects of publication practices, such as a more national and regional orientation, less publication in serials, and a different pace of theoretical development also vary between the Sciences and the Social Sciences and Humanities (Nederhof, 2006). However, the most significant differences lie in the number of co-authored papers (see e.g. Bourke, 1997; Harzing, 2010; Larivière, Gingras and Archambault, 2007), which in turn positively influences both the number of publications (see amongst many other Börner, Dall'Asta, Ke, and Vespignani, 2005; Katz and Martin, 1997) and the number of citations (see e.g. Glänzel and Thijs, 2004).

The first metric correcting for disciplinary differences was the hI-index as published by Batista, Campiteli and Kinouchi (2006). Batista et al. (2006) divide the h-index by the average number of authors in the h-core set and argue that this adjustment corrects for disciplinary differences. We agree with their basic rationale as co-authorship not only allows academics to write *more* papers, but also increases citations *to* these papers (see e.g. Glänzel and Thijs, 2004) as co-authorship is likely to increase both self-citations and citations from the co-authors' combined research networks. However, the operationalisation of Batista's metric has serious limitations as it only includes publications that are already in the h-core and severely punishes authors who, in conjunction with many single-authored papers, publish an incidental paper with many co-authors. It also leads to anomalous situations of a declining hI-index when a paper with many co-authors enters the h-core. Therefore, in 2007 we introduced the hI,norm through the Publish or Perish program (Harzing, 2007). The hI,norm first normalizes citations for *each* paper by dividing the number of citations by the number of authors for that paper, and only then calculates the h-index of the *normalized* citation counts. This metric more accurately accounts for co-authorship effects and allows for non h-core articles to enter the h-core. It is also much closer to the spirit of the original h-index. A third individual h-index, Schreiber's (2008) h_m-index, uses fractional paper counts instead of reduced citation counts to account for shared authorship of papers, and then determines the multi-authored h_m-index based on the resulting effective rank of the papers using undiluted citation counts. However, this metric is cumbersome to calculate an interpret is highly correlated (r=0.943) with the hI,norm in the sample used in our empirical illustration below.

Antonakis and Lalive (2008) propose the IQp index in which a discipline correction is based on the average Thomson Reuters journal impact factor for the three subject areas in which the author is most highly cited. This correction, however, necessitates a very time-consuming, manual data collection that has to be repeated for every individual. Moreover, Antonakis and Lalive show that the resulting correction factor is very similar to Batista et al.'s (2006) correction for co-authors. Although Antonakis and Lalive claim that correcting for the number of co-authors is more labour-intensive than their own approach, we would argue the reverse is true as author correction can be done automatically. Finally, Kaur, Hoang, Sun, Possamai, JafariAsbagh, Patil, and Menczer (2012) introduce the h_f. h_f is calculated by dividing the citations for each paper by the average number of citations in the year and discipline in question and then calculate the h-index from the resulting corrected citations. Kaur, Radicchi and Menczer (2013) further simply this by defining Hs, which is calculated by dividing an academic's regular h-index by the average h-index for the discipline. Although a useful way to accommodate for disciplinary differences, its calculation runs into two practical problems. First, it necessitates reliable discipline averages, which are not generally available in citation databases. Second, it requires the user to be able to accurately define the discipline for every academic they are searching for, a condition that is not normally satisfied.

In addition to the studies that explicitly refer to discipline correction, there are a very wide range of other proposed corrections for the h-index that adjust for co-authorship. Some of these (see e.g. Hagen, 2009) share the credit based on the order of the authors. This is problematic as conventions with regard to authorship order differ substantially between disciplines. Other attempts give either more credit to the highest performing author in terms of overall citations or citations per paper (e.g. Tol, 2011) or only credit a paper to the h-index for the senior author (e.g. Hirsch, 2010). These types of metrics have two significant disadvantages. First, they assume that citations to the focal article should count more or even only for academics who have been more successful in the past. However, the article in question might well be based on theoretical advances by the "junior" author. As such these metrics create a substantial disadvantage to early career researchers. Second, these metrics are rather complicated to calculate even for a single author, and become very unwieldy for academics with a large number of co-authors. Hence they fail the practical applicability test. Finally, their results are not easy to interpret for a lay audience and hence unlikely to achieve the wide acceptance that has been accorded to the original h-index.

In sum, although reliable normalisation by sub-discipline would be ideal from a theoretical standpoint, the practical problems in calculating a discipline-corrected metric are substantial. In contrast, an individual h-index can very easily be calculated for any of the traditional citation databases. Correction for the number of co-authors is likely to remove substantial variation *across* disciplines and hence an individual h-index might be a good approximation of a discipline neutral h-index. Moreover, an individual h-index can also accommodate differences *within* disciplines by recognising academics that typically publish alone or with few co-authors. As the hI,norm is easy to calculate and adjusts for co-authorship in a much more appropriate way than Batista's individual h-index, we will use hI,norm as the basis for our new metric.

A second step is to correct for differences in career length. Although there are a range of metrics, such as the contemporary h-index (hc), that correct for the age of papers, there are few metrics that attempt to correct for career length. This might be because differences in career length or academic age can be accommodated very easily by dividing the h-index by the number of years an academic has been publishing[1]. This is exactly what Hirsch proposed in his original article with Hirsch's m (Hirsch, 2005). Burrell's (2007) h-rate follows the same calculation. Antonakis and Lalive (2008) suggest defining academic age or career length as the time elapsed since acquiring one's doctorate. However, this presents data availability problems and might re-introduce a disciplinary bias as academics in the (Life) Sciences are more likely to publish *during* their PhD than academics in the Humanities and Social Sciences and publication delays are generally longer in the latter disciplines. We therefore follow Hirsch's original suggestion to correct for career length by dividing the h-index by the number of years an academic has been publishing.

Following our discussion above, the hIa-index is thus calculated by dividing Harzing's Publish or Perish hI-norm (Harzing, 2007) by the number of years that an academic has been publishing. As such, the hIa-index measures the average number of single-author equivalent h-index points that an academic has accumulated in *each* year of their academic career. A hIa-index of 1.0 means that an academic has *consistently* published one article per year that, when corrected for the number of co-authors, has accumulated enough citations to be included in the h-index. We expect that for most of the world's academics this metric will lie *well* below 1.0. Someone who co-publishes with others will *not* need to publish more articles to achieve the same hIa-index as an academic who publishes single-authored articles. However, the co-authored articles will need to gather more citations to become part of the hIa-index as the article's citations are divided by the number of co-authors.

Empirical illustration of the hIa-index

Methods

We use Scopus data for 146 Associate Professors and Full Professors at the University of Melbourne – one of the world's top-30 universities according to the THE World University ranking – to illustrate the usefulness of our hIa-index[2]. Our sample includes two Associate Professors and two Full Professors in all 37 disciplines represented at this university[3], grouped into five major disciplinary fields:

- Humanities: Architecture, Building and Planning, Culture and Communication, History, Languages and Linguistics, Law (19 observations),
- Social Sciences: Accounting and Finance, Economics, Education, Management and Marketing, Psychology, Social and Political Sciences (24 observations),
- Engineering: Chemical and Biomolecular Engineering, Computing and Information Systems, Electrical and Electronic Engineering, Infrastructure Engineering, Mechanical Engineering (20 observations)
- Sciences: Botany, Chemistry, Earth Sciences, Genetics, Land and Environment, Mathematics, Optometry, Physics, Veterinary Sciences, Zoology (44 observations),
- Life Sciences: Anatomy and Neurosciece, Audiology, Biochemistry and Molecular Biology, Dentistry, Obstretics and Gynaecology, Ophthalmology, Microbiology, Pathology, Physiology, Population Health (39 observations).

[1] Academic age could be adjusted if a first publication occurred years before a steady stream of research output materialised, as might the case for a published conference paper or a book review.

[2] We also collected data for Google Scholar and the Web of Science (ISI); the results for these databases were very similar in terms of the hIa-index's attenuation of differences between disciplines and career length. The average hIa-index was very similar in Scopus and ISI, but was approximately 30-35% higher in Google Scholar.

[3] Two professors in Law and Physics had to be removed from the final sample as their publication patterns were very uncharacteristic of their field.

The larger number of observations in the Sciences and Life Sciences is a reflection of the dominance of these disciplines at the University of Melbourne. Although grouping sub-disciplines into major disciplinary fields is always fraught with problems [4], it is important to note that calculation of our hIa-index does not depend on discipline classification. While below we illustrate the usefulness of the hIa-index in disciplinary comparisons, a choice of discipline is not needed to calculate the hIa-index as long as the number of authors per paper is available as a proxy for disciplinary differences.

Within each sub-discipline, individuals were randomly selected, although a preference was given to individuals with unique names to avoid problems with author disambiguation. Where possible, one male and one female academic were selected at each level. However, in some disciplines this proved to be unfeasible, because of the shortage of female academics at senior levels. Search queries were refined on an iterative basis through a detailed comparison of the results for the three databases. Searches for Google Scholar were conducted through Publish or Perish (Harzing, 2007), a program that retrieves and analyses academic citations. It is used mainly in conjunction with Google Scholar, but can also parses citation data from Microsoft Academic Search and can import a variety of formats, including Scopus and ISI data. Searches for Scopus and ISI were conducted in their native interfaces, exported and subsequently imported into Publish or Perish to allow for calculation of the various citation metrics and exporting to Excel and SPSS for further analysis.

Our sample provides an excellent test case for the new hIa-index as all academics work for the same university, Australia's best performing institution in the national research evaluation (Hare, 2012). The University of Melbourne displays excellence in most disciplines and has very rigorous promotion procedures. Even within the same university one might still expect variance in individual academics' hIa indices as publication and citation metrics are not the only criteria for promotion, and promotion criteria only constitute minimum standards. However, the hIa-index should remove much of the variance that is attributable simply to disciplinary and career length differences.

Results

Table 1 compares the average h-index in the five major disciplinary fields. There are large differences between disciplines, with Humanities at the bottom, followed by a second group that includes the Social Sciences and Engineering, with the Sciences and Life Sciences forming a third group. However, there are also large differences between disciplines in terms of the average number of authors per paper. These differences follow broadly the same pattern as the differences in the h-index. Finally, we also find differences in terms of the years academics have been active, with academics in the Sciences and Life Sciences having a longer publishing career than academics in the other disciplines.[5]

[4] For instance, Veterinary Sciences, Land & Environment, and Earth Sciences could have been classified into a separate major discipline of Environmental Sciences. However, their h, hIA and author per paper metrics were very similar to the Sciences; hence they were merged into the Sciences category. Architecture, Building & Planning displays similarities with Engineering, the Social Sciences and the Humanities. However, our selected academics were all in the Architecture/Design field, which is more aligned with the Humanities tradition; hence they were classified into the Humanities cluster.

[5] Apart from sample idiosyncrasies, this may have been caused by three factors. First, academics in the (Life) Sciences normally start publishing during their PhD, whereas this is less common for academics in other disciplines. Second, academics in the (Life) Sciences often have a longer career trajectory, with most academics taking on one or more postdocs before appointment as Assistant Professor. Finally, in Engineering, the Social Sciences and Humanities, academics might well have early career publications in outlets not included in Scopus, such as books or conference proceedings, or in journals not currently included in Scopus.

*Table 1: H-index compared with hIa-index for different disciplines**

Discipline	Average h-index	Average # of authors per paper	Average academic age	Average hIa-index
Humanities (n=19)	3.21 [a]	1.90 [a]	18.16 [a]	0.14 [a]
Social Sciences (n=24)	9.83 [b]	2.62 [ab]	19.54 [a]	0.37 [b]
Engineering (n=20)	12.50 [b]	3.89 [bc]	19.90 [a]	0.34 [b]
Sciences (n=44)	22.31 [c]	4.66 [cd]	29.36 [b]	0.40 [b]
Life Sciences (n=39)	23.95 [c]	6.22 [d]	25.69 [b]	0.43 [b]
F-statistic	33.894***	15.300***	10.427***	12.478***
Mean (SD)	16.92 (10.92)	4.33 (2.82)	23.86 (9.02)	0.36 (0.18)
Range	0-48	1.00-23.05	5-46	0.00-1.00

* Means with the same superscript are not significantly different at p=0.05 (Tukey B test), *** p < 0.001

The influence of career length and number of co-authors on the h-index is clearly illustrated in our sample by the strong correlations between career length and the h-index (r=0.567***) and between the number of co-authors and the h-index (r=0.535***). These two explanatory factors are also largely independent and together explain well over half of the variance in the h-index in our sample. As Table 1 shows, when we correct for disciplinary differences and career length through the hIa-index, means for the Social Sciences, Engineering, Sciences and Life Sciences are no longer significantly different. The only discipline that still shows a significantly lower mean is the Humanities, reflecting the different role of citations in the Humanities (Hellqvist, 2010). However, even for the Humanities, the difference with the other disciplines has become much smaller. The average h-index for the Sciences and Life Sciences is more than seven times as high as for the Humanities, whereas for the hIa-index, the metrics for Sciences and Life Sciences are only three times as high as for the Humanities. Figure 1 illustrates visually how the hIa-index evens out differences between disciplines.

Figure 1: h-index compared with hIa index for different disciplines

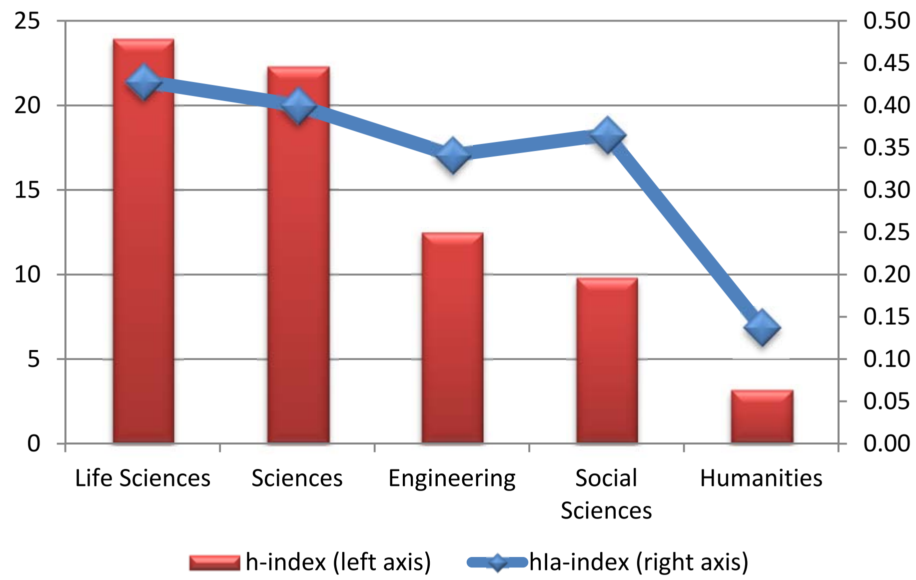

Table 2 shows that the hIa-index also removes a substantial part of the difference between different levels of appointment, with the average hIa-index for Associate Professors standing at 83% of that of Professors, whereas their h-index is only 61% of the Professorial average. Finally, the hIa-index also removes the marginally significant difference between male and female academics, because it corrects for gender differences in academic age and gender representation across disciplines.

Table 2: h-index compared with hIa index by levels of appointment and gender

Level of appointment and gender	Average h-index	Average hIa-index	Average academic age	Average # of authors per paper
Assoc. Professor (n=74)	12.86	0.33	20.69	3.90
Professor (n=72)	21.10	0.40	27.11	3.87
	t=4.902***	t=2.314*	t=4.592***	t=0.123
Female (n=64)	15.06	0.35	21.80	3.73
Male (n=82)	18.38	0.37	25.46	4.00
	t=1.835†	t=0.867	t=2.481*	t=1.013

† $p < 0.10$, *, $p < 0.05$, **, $p < 0.01$, *** $p < 0.001$

A final way to illustrate the effect of the hIa-index in terms of correcting for disciplinary and career length differences is to look at the top-10 academics in our sample when ranked by h-index and hIa-index (see Table 3). The top-10 by h-index shows a very homogenous group of Life Science academics, who are at a Professorial level, predominantly male and have an average academic age of 34.4 years. The top-10 by hIa-index incorporates a wider range of disciplines and has a perfectly balanced gender and level of appointment representation. The average academic age is much shorter at 20.7 years. This demonstrates that the h-index is strongly influenced by longevity and disciplinary differences in the number of co-authors, whereas the hIa-index provides a more level playing field for younger academics and those working in disciplines where co-authorships are less common.

Table 3: Discipline, gender, level of appointment and academic age of the top-10 highest ranked academics by h-index and hIa-index

Top-10 by h-index				**Top-10 by hIa-index**			
Discipline	**Gender**	**Level**	**Years**	**Discipline**	**Gender**	**Level**	**Years**
Life Sciences	M	Prof	21	Social Sciences	F	Prof	17
Life Sciences	M	Prof	41	Social Sciences	M	Prof	23
Life Sciences	F	Prof	24	Life Sciences	F	Assoc	27
Life Sciences	M	Prof	37	Life Sciences	F	Assoc	21
Life Sciences	F	Prof	35	Sciences	M	Prof	29
Life Sciences	M	Prof	37	Life Sciences	M	Assoc	13
Life Sciences	M	Prof	30	Life Sciences	F	Prof	19
Life Sciences	M	Prof	43	Life Sciences	M	Prof	21
Life Sciences	F	Assoc	27	Life Sciences	M	Assoc	18
Sciences	M	Prof	29	Sciences	F	Assoc	19
Average h-index 38				**Av. hIa-index 0.75**			

To conclude, Table 4 presents the correlation matrix for our new hIa-index with a range of traditional metrics. The h-index is strongly correlated with the number of citations (r=0.898) as well as the number of papers (r=0.822) and academic age (r=0.567). As such the h-index mainly reflects disciplinary differences in publication quantity and the number of citations received, as well as the simple longevity of the academic. In contrast, the hIa-index only shows moderate correlations with both the number of citations (r=0.514) and the number of papers (=0.426) and – as expected for a career length independent metric – is unrelated with academic age. Finally, although the hIa-index and the traditional h-index are significantly correlated, suggesting convergent validity, their correlation is modest, thus indicating that the hIa-index adds significant information over and above the h-index.

Table 4: Correlations among the hIa-index, the h-index, number of papers, number of citations and academic age

	hIa	h-index	# papers	# citations	Academic age
hIa	-	.642***	.426***	.514***	-.023
h-index	.642***	-	.822***	.898***	.567***
# papers	.426***	.822***	-	.778***	.524***
# citations	.514***	.898***	.778***	-	.487***
Academic age	-.023	.567***	.524***	.487***	-

*** $p < 0.001$

Evaluation

Like any metric, the hIa has its limitations and therefore should not be used on its own. We would recommend that it be used in conjunction with the regular h-index and the total number of citations. Although we argue that it provides a more reliable comparison between academics in different disciplines and at different career stages, there are some circumstances in which it might not provide optimal results. As to be expected, this happens mainly at the extremes of the distribution.

In terms of co-authorship extremes consist of authors who only or largely publish single-authored work and those who consistently publish with a large number of authors. Those with a high proportion of single-authored articles will by definition have an individual h-index that is very close or even equal to their h-index and hence will have a relatively high hIa compared to the original h-index. However, as these authors will typically publish only a small number of papers, the hIa simply gives them the credit that is due for these papers. The other extreme consists of academics with a very large number of co-authors. For academics involved in collaborative projects with hundreds of co-authors (as in experimental physics) it might become impossible for articles to acquire enough citations to become part of the individual h-index and hence hIa. However, this is easily resolved by limiting the total number of co-authors to be considered in the calculation. The Publish or Perish implementation of the individual h-index limits the maximum number of authors considered to 50. A sensitivity analysis showed that varying this upper limit between 10 and 50 impacted on the hIa only for a couple of academics in our sample, and even for these academics only marginally so.

In terms of career stage, very junior academics that happen to publish several single-authored articles out of their PhD within a short space of time will have a very high hIa, without any realistic expectation that this pattern will continue. However, in this case the regular h-index as well as the total number of citations will provide a "sanity check". Senior academics nearing the end of their career will see their hIa decline with passing years as it becomes more and more difficult to increase an already high h-index. That said, the hIa uses the individual h-index as its basis, and this h-index might still increase as it approximates the regular h-index with increasing citations to multi-authored papers. Moreover, this limitation is easily accommodated by including the total number of citations in the evaluation.

By definition only a small number of academics will operate at the extremes of the distribution and these cases are easily addressed by incorporating the original h-index and the number of citations. However, for the vast majority of the academics the hIa provides a more reliable indicator of relative academic performance than currently available metrics.

Conclusion

In this article we introduced a new metric, the hIa-index that reflects the annual increase in an academic's individual h-index. Based on an empirical example of 146 academics in five major disciplines at different career stages, we showed that the hIa-index attenuates h-index differences attributable to disciplinary co-authorship practices and career lengths. As for other research metrics, the hIa-index should never be used as the sole criterion to evaluate academics. Another crucial question that should always be asked is: "Has the scholar asked an important question and investigated it in such a way that it has the potential to advance societal understanding and well-being?" (see e.g. Adler and Harzing, 2009). However, we conclude that the hIa-index provides a more reliable comparison between academics in different disciplines and at different career stages than the h-index.

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